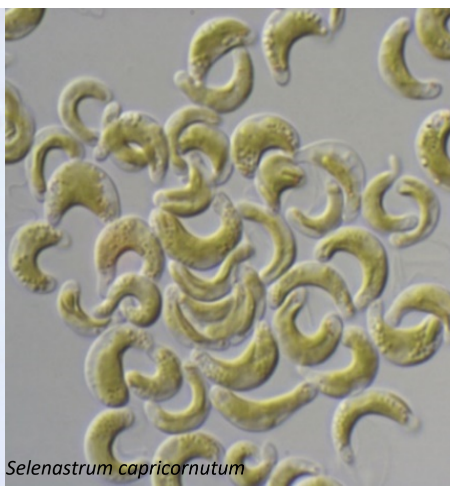
Thunder Bay Area of Concern Beneficial Use Impairment Assessment Report

Degradation of Phytoplankton and Zooplankton Populations

Ceriodaphnia dubia


Selenastrum capricornutum


Daphnia magna

December, 2018

Cover photos: Plankton commonly found in the Thunder Bay Area of Concern.

1) *Ceriodaphnia dubia*. Berner, D.B. 1986. Taxonomy of Ceriodaphnia (Crustacea: Cladocera) in U.S. Environmental Protection Agency cultures. EPA/600/4-86/032. Copyright © 2003-2013 Center for Freshwater Biology, Department of Biologcal Sciences University of New Hampshire, Durham, NH 03824 USA.

2) *Selenastrum capricornutum*. By (Korshikov) Nygaard, Komárek, Kristiansen & Skulberg (1987). Source: https://www.ccap.ac.uk/strain_info.php?Strain_No=278/4. Copyright CCAP 278/4.

3) *Daphnia magna*. "Female Daphnia magna with a clutch of asexual eggs. The animal is about 4 mm long." By Dieter Ebert, Basel, Switzerland. Source: https://commons.wikimedia.org/wiki/File:Daphnia_magna_asexual.jpg. Licensed under CC BY-SA 4.0.

Summary

Degradation of Phytoplankton and Zooplankton Populations was identified as a beneficial use impairment (BUI) in the Thunder Bay Area of Concern (AOC) in the report Stage 1: Environmental Conditions and Problem Definition (Thunder Bay Remedial Action Plan Team 1991) on the assumption that plankton communities and populations in the Kaministiquia River and in the Thunder Bay harbor would be degraded due to poor water quality from industrial effluent and the introduction of invasive species. The subsequent report Stage 2: Remedial Strategies for Ecosystem Restoration (Thunder Bay Remedial Action Plan Team 2004) changed this status to 'Requires Further Assessment'.

Because no delisting criteria were developed for this BUI, the attached technical report Assessment of the Degradation of Phytoplankton and Zooplankton Populations Beneficial Use Impairment in the Thunder Bay Area of Concern completed by the Ministry of the Environment, Conservation and Parks (MECP)[1] is a screening level assessment, which provides a general indication of the potential for ecological risk. The conclusion of this screening level assessment is that the phytoplankton and zooplankton populations are not impaired in the Thunder Bay AOC.

In this assessment, multiple lines of evidence, with emphasis on the issues originally identified, were examined in a pragmatic manner; and a determination of status was made based on available information and data as it pertains to the health of plankton in the Thunder Bay AOC. Examined lines of evidence included past and current nutrient assessments; a top-down, bottom-up approach (assessment of water quality indicators and fish health); toxicity of industrial effluents; industrial and municipal loading levels; industrial and municipal treatment upgrades and process changes; industrial closures; and invasive species.

The MECP report (Appendix 1) assessed the key factors that influence the health of the plankton population and determined that there is no reason to suspect impairment of the plankton populations within the AOC. Impaired plankton populations can be evident when there is not enough plankton available to form the basis of a healthy food web, or when there is too much plankton and algae blooms form (algae are a form of plankton). The industrial landscape of the Thunder Bay AOC has changed substantially since the inception of the RAP program, and nutrient and contaminant loading have declined from original levels. The assimilative capacity of the large Kaministiquia River and receiving oligotrophic Lake Superior have provided an environment that is not prone to algal blooms, and which supports a healthy fish population.

The Department of Fisheries and Oceans also undertook an assessment which summarized all available plankton data from the Thunder Bay area and compared it to that from other embayment, coastal and offshore areas in Lake Superior (Currie *et al*. 2015). Their findings indicate that phytoplankton biomass and species composition varies, but is generally in the oligotrophic range, and that Thunder Bay stations have a higher biomass than other stations at times. The report also notes that embayments in Lake Superior, such as Thunder Bay, are warmer and have slightly higher nutrient level which results in higher overall zooplankton densities and biomass than open water. Historic data shows that Thunder Bay generally supports the highest zooplankton populations in Lake Superior; however, total phosphorous and chlorophyll results suggest that Thunder Bay is still usually in the oligotrophic range.

[1] Ontario's Ministry of Environment and Climate Change was renamed on June 29, 2018 to the Ministry of the Environment, Conservation and Parks.

Consistent with the overall finding of the Lake Superior Partnership that the lower food web in Lake Superior is robust and stable, Currie *et al.* (2015) noted that the zooplankton community in the Thunder Bay area of Lake Superior appears to have been relatively stable since the early 1970s.

Key findings include:

- Despite the elevated levels of total phosphorus (TP), primarily in the deltic area of the Kaministiquia River, nuisance algae has not been reported during the monitoring surveys. This is likely due to the capacity of the lake to dilute concentrations of TP below the level that would cause algal blooms.
- The industrial landscape of the AOC has changed substantially in the past decades in that several industries that contributed high loadings of nutrients, BOD_5, and other contaminants, have closed and thereby lessened the load to the receiving environment.
- In terms of the remaining point sources of nutrients and contaminants from the Resolute Forest Products, Ontario Power Generation – Thunder Bay Thermal Generating Station, and Thunder Bay Water Pollution Control Plant, treatment upgrades and/or process changes at these facilities have significantly improved effluent quality which is routinely monitored for various contaminants and acute and chronic toxicity tests.
- The study area is not phosphorus limited, and chlorophyll-*a* concentrations are not likely to result in undesirable levels of algae.
- Thunder Bay supports the highest zooplankton populations in Lake Superior and has been stable since the early 1970s.
- The AOC supports a more diverse fish community than adjacent areas.
- Fish populations appear to be stable between the inner and outer harbour.

For more detailed information, appended to this summary is the following document:

Appendix 1: George TK. 2016. Assessment of the degradation of phytoplankton and zooplankton populations beneficial use impairment, Thunder Bay Area of Concern. Ontario Ministry of the Environment and Climate Change. February 8, 2016.

References:
Currie, W.J.S. Bowen, K.L., Niblock, H.A. and Koops. M.A. 2015. Compilation and evaluation of historical data and samples to support assessment of phytoplankton and zooplankton populations in Great Lakes Areas of Concern. Can. Tech. Rep. Fish. Aquat. Sci. 3150: v + 152p.

Stage 1: Environmental Conditions and Problem Definition (Thunder Bay Remedial Action Plan Team 1991)

Stage 2: Remedial Strategies for Ecosystem Restoration (Thunder Bay Remedial Action Plan Team 2004)

Appendix 1:
Assessment of the Degradation of Phytoplankton and Zooplankton Populations Beneficial Use Impairment

Thunder Bay Area of Concern

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February 8, 2016

Table of Contents

Executive Summary

For decades practitioners working on Great Lakes Areas of Concern (AOCs) have been discussing how to best address the '*Degradation of Phytoplankton and Zooplankton Populations'* beneficial use impairment (BUI). Not only is there considerable variation in defining the issue of the identified AOCs, but there are also inconsistencies in the approaches for monitoring and reporting the BUI. Thunder Bay is one of five AOCs that have the plankton BUI listed as 'requiring further assessment.' The initial identification of the BUI in Thunder Bay was based on the assumption of eutrophication and the introduction of invasive species altering plankton populations; however the claim of an altered population was not substantiated by a baseline study. The intention of this report was to assess the current status of the plankton BUI by using an approach that deviates from the approaches previously taken. Different lines of evidence, with emphasis on the issues originally identified, were examined in a pragmatic manner, and a determination of status was made based on available information and data as it pertains to the health of plankton in the Thunder Bay AOC. Examined lines of evidence included past and current nutrient assessments; a top-down, bottom-up approach (assessment of water quality indicators and fish health); toxicity of industrial effluents; industrial and municipal loading levels; industrial and municipal treatment upgrades and process changes; industrial closures; and invasive species.

There have been several studies which have characterized the nearshore and offshore zones of Thunder Bay (Hopkins 1986, Simpson 1987, Anderson 1986, Boyd 1990, Richman 2004, Benoit *et al*. 2012, George 2012). This assessment focused mainly on the nearshore zone of the Thunder Bay AOC, as the plankton would be most likely influenced by anthropogenic inputs in this area. Generally the studies found the nutrient levels to be highest in the deltic area of the Kaministiquia River, where in most cases, the total phosphorus (TP) levels exceed the TP-Provincial Water Quality Objectives (PWQO - 20 µg/L in lakes and 30 µg/L in rivers). Despite the elevated levels of TP, nuisance algae has not been reported during the monitoring surveys, which is likely due to the capacity of the Lake to dilute concentrations of TP below the level that would cause algal blooms.

The industrial landscape of the AOC shoreline has changed substantially in the past decades. Several industries, that contributed high loadings of nutrients, BOD_5, and other contaminants, have closed and thereby lessened the load to the receiving environment. The three remaining point sources of nutrients and contaminants to the Thunder Bay AOC include Resolute Forest Products, Ontario Power Generation – Thunder Bay Thermal Generating Station, and the Thunder Bay Water Pollution Control Plant. Treatment upgrades and/or process changes at these facilities have significantly improved effluent quality. The improvement in effluent has been observed in the outcome of acute and chronic toxicity tests that are regulated through Ontario's Effluent Monitoring and Effluent Limit Regulations. There have been no acute toxicity violations since 2006 at Ontario Power Generation, and very seldom are the potential for chronic effects observed at concentrations less than 100% effluent. There has been minimal acute

toxicity over the sampling period of 2002 to 2015 at Resolute Forest Products. Where acute violations (failures) did occur, they were most often due to a specific operational change (e.g., shutdown). Recent chronic toxicity tests (past 1.5 years) from Resolute Forest Products have shown minimal to no chronic toxicity to zooplankton and phytoplankton, respectively. Prior tests from the combined-mill outfall had demonstrated the potential for chronic impairment to plankton.

To obtain a broader view of the AOC, a top-down and bottom-up approach was adopted using water quality data (Benoit *et al*. 2012) and fish community index data (Foster 2012, Marshall 2015) to determine the status of the plankton trophic level. In addition, the approach was used as a screening level assessment to determine if further investigation was warranted for the plankton BUI. From the bottom-up, it was shown that the study area was not phosphorus limited, and that chlorophyll-*a* concentrations were not likely to result in undesirable levels of algae (Benoit *et al*. 2012). From the top-down, current data suggests that the Thunder Bay AOC supports a more diverse fish community than adjacent areas. Generally, it was determined that there was no basis to continue with a full plankton assessment.

A concern that was originally identified was the introduction of aquatic invasive species, specifically the zebra mussel and the spiny water flea (Thunder Bay RAP 1991, 2004). Dreissenid mussels (which include zebra mussels) are not wide-spread through Lake Superior due to the cold water temperatures; however they are present in specific nearshore areas, including Thunder Bay. Fish communities in Lake Superior, both nearshore and offshore, are primarily supported by a diet of *Mysis* and *Diporeia*. In the lower Great Lakes, populations of these macroinvertebrates have declined as a result of the abundance of Dreissenid mussels, but this has not been the case in Lake Superior. With respect to the spiny water flea (*Bythotrephes*), limited studies have been conducted in Lake Superior and further research is required to fully understand this invasive species. Trophic food web studies (Gamble *et al*. 2011a, Gamble *et al*. 2011b, Keeler *et al*. 2015) have shown that some fish species, predominantly Cisco, have incorporated *Bythotrephes* into their diet; in this case the adopted feeding behaviour may serve as a top-down control of the invasive population (Keeler *et al*. 2015). Overall, based on the food web configuration at a low level of prey diversity, there is system stability (Gamble *et al*. 2011b). Regardless of the indications of adaption to the invasive species, the issue is a priority and there are a number of provincial, federal, and binational initiatives that focus on monitoring and prevention.

The assessment of the key factors that influence the health of the plankton population has demonstrated that there is little basis to continue the assessment of this BUI. The industrial landscape of the Thunder Bay AOC has changed substantially since the inception of the RAP program, and nutrient and contaminant loading have declined from original levels. The assimilative capacity of the large Kaministiquia River and receiving oligotrophic Lake Superior have provided an environment that is not prone to algal blooms, and which supports a healthy fish population. At this time, it is recommended that the ‘requires further assessment’ status of the Degradation of Phytoplankton and Zooplankton Populations BUI be removed. The lower

food web of the lake, as a whole, will continue to be assessed through the Lake Superior Partnership by way of the Coordinated Science and Monitoring Initiative.

List of Tables

List of Figures

1.0 INTRODUCTION

Biological assemblages are complex and respond in unpredictable ways to a wide range of physical and biological conditions. As such, setting qualitative and quantitative targets to assess the status of these assemblages can be difficult. For decades, practitioners working on the Great Lake Areas of Concern (AOCs) have been discussing how to best address the '*Degradation of Phytoplankton and Zooplankton Populations'* beneficial use impairment (BUI). Not only is there considerable variation in defining the issue of the identified AOCs, but there are also inconsistencies in the approaches for monitoring and reporting the BUI. Further to that, there is often disagreement as to the validity of one approach over another. In the last decade there has been much discussion, in the form of workshops (section 1.1), meetings, and articles/reports (George and Boyd 2007, Benoit *et al*. 2012), regarding challenges associated with the plankton BUI.

Thunder Bay is one of five AOCs with the plankton BUI listed as 'requiring further assessment.' In many cases, this status designation is a result of the beneficial use not being properly assessed initially by community and population analysis. In the case of Thunder Bay, the initial identification of the BUI was based on the assumption of eutrophication and the introduction of invasive species altering plankton populations. Generally, there has been no clear consensus on the best approach to collecting further information to address this BUI; a scenario that exists for most other AOCs dealing with this BUI. The intention of this paper is to assess the status of the plankton BUI by investigating the issues that resulted in the BUI being listed originally, as well as available data that both directly and indirectly addresses the status of the BUI. Different lines of evidence will be examined in a pragmatic manner, and a determination of status will be made based on available information and data as it pertains to the health of plankton in the Thunder Bay AOC.

1.1 Beneficial Use Workshops

Since 2004 there have been several collective efforts, in the form of workshops, to address challenges related to the BUIs. Specifically, experts have been brought together to discuss the plankton BUI and derive solutions to effectively monitor and report on this indicator within the AOC program. A common denominator of the various discussions is the lack of guidance in assessing the plankton BUI. Although many approaches have been proposed, a clear consensus was rarely achieved both within and among workshops. However, the lastest workshop in 2014 suggested that a pragmatic lines of evidence approach was the favoured amongst AOC and RAP practioners.

1.1.1 2004 BUI Monitoring Workshop

In 2004, the Ontario Ministry of the Environment hosted a BUI Monitoring Workshop in Guelph, ON. Experts from different agencies were invited to attend with the purpose of achieving consensus on the type and quantity of information required to report progress towards delisting (George *et al*. 2004). In addition, the intention was to establish agreement on survey design principles of the BUI-focused monitoring plan as a template for agencies who agreed to undertake various components of the plan. There was an expectation that following the

workshop the generic recommendations would be used in the development of specific monitoring plans for each AOC.

A break-out session was held for each BUI, with special emphasis on those within the mandate of the MOE. With respect to the degradation of phytoplankton/zooplankton populations BUI, participants generally agreed that there was not enough guidance on what was intended by this beneficial use and how it should be measured. Group discussions concluded that several of the issues under the plankton BUI could be dealt with under the Eutrophication and Undesirable Algae BUI. In terms of assessing the relevance of this BUI on an ecological basis, it was suggested that a decline in fish populations or degradation of aesthetics (e.g., algae blooms) might be a more effective way of describing rapid shifts in plankton populations; the suggestion of a top-down, bottom-up approach ensued from this discussion. Overall it was agreed that sharing information between the AOCs was essential.

1.1.2 2010 Phyto/Zooplankton Workshop

The 2010 Phyto/Zooplankton Expert Workshop was held in Burlington, ON and experts from several provincial and federal government agencies, academia, and consulting were invited to attend. The purpose of the workshop was to determine how the degradation of phytoplankton and zooplankton BUI could be assessed in AOCs where data was poor or lacking within a two year timeframe. The ultimate goal of the workshop was to enable Great Lakes managers to determine the status of the BUI so that decisions could be made on delisting targets. A practical and scientifically defensible approach to assessing the lower trophic levels at all AOCs is a valuable tool in the creation of a management framework for future decision making.

There were several highlights and conclusions drawn from the two-day workshop. Overall, it was agreed that the current definition of the plankton BUI is not clear, and that a consistent unified approach for assessing the BUI amongst all the applicable AOCs would be desirable. The approach to be taken would be to assess plankton in terms of both structure and function across a gradient of environmental conditions or using a reference condition for comparison. The primary action to manage the plankton BUI, in most AOCs, is nutrient loading control. However, it was also expressed that other BUIs such as eutrophication and undesirable algae, and fish community structure, while related, are not necessarily direct indicators of the health of the plankton population. Other novel techniques such as mapping energy flow patterns using isotopes and zooplankton fatty acid measurements were flagged as being worth consideration. It was recognized that analysis of samples requires human, analytical, and taxonomic resources, which can be costly. As such, it was suggested that a steering committee be formed, comprised of both scientists and management, to coordinate the approach and ensure optimal use of resources; currently knowledge suggests the formation of this committee did not occur.

1.1.3 2014 Remedial Action Plan Implementation Workshop

The 2014 Remedial Action Plan Implementation Workshop, held in Burlington, ON, was intended to build on discussions from earlier workshops to reflect on progress and discuss practical strategies for some of the continuing challenges with the AOC program. Once again, it

was highlighted that even at the data rich Bay of Quinte AOC, there remained challenges and a series of debateable questions.

The AOCs with the “requires further information” designation for the plankton BUI were highlighted at this Workshop, and the most current approach implemented at the respective areas were presented: Thunder Bay AOC “top-down, bottom-up” approach (described in section 4.1); lines of evidence approach for Toronto AOC; and an upstream, midstream, and downstream comparison approach for the Detroit River AOC. For the most part, workshop participants were in favour of a line of evidence approach for addressing the plankton BUI. The functionality aspect of approaches that use lines of evidence (the top-down, bottom-up approach included) was noted as useful. It was from discussions at this workshop that it was determined that the lines of evidence approach that incorporated both direct and indirect measures of biotic health would be implemented as a means to redesignate the plankton BUI in Thunder Bay.

2.0 PLANKTON POPULATION AND NUTRIENT ASSESSMENTS

There has been few plankton studies conducted in the Thunder Bay AOC. Generally, where plankton sampling has been undertaken, it has been part of a bigger sampling effort where the overall quality of the system was being assessed. Outlined below are Ontario Ministry of the Environment studies, conducted since the 1980s, that have measured plankton abundance and/or levels of nutrients (specifically TP) in surface water.

Off-shore water quality and plankton studies have been conducted by other government and academic institutions (Reavie *et al*. 2013, Kelly *et al*. 2015). Although the results do not speak specifically to the status of the BUI, they do provide an indication of the diversity and density of plankton populations in Lake Superior, as well as a background nutrient profile of the surface water.

2.1 Phytoplankton Monitoring Program

In 1972, a phytoplankton monitoring program was implemented at the drinking water intake at Bare Point; general water quality parameters were added to the program in 1979 (Hopkins 1986). The main purpose of the program was to assess the nearshore water quality over time with emphasis on tropic indices. Untreated water samples were collected weekly, year-round and analyzed for chlorophyll, phosphorus, nitrogen, silica and chloride. For phytoplankton, weekly samples were combined and analyzed as monthly composites.

Over the period of 1980 to 2013, the mean annual total phosphorus concentration was 4.85 ± 1.73 µg/L and did not change monotonically. Mean annual chlorophyll-*a* also did not change over time (0.97 ± 0.27 µg/L), although concentrations steadily decreased between 2000 and 2013. Between 1983-2013, mean annual algal density was relatively low and in most years was dominated by diatoms, followed by cryptophytes and chrysophytes. Total algal density tended to be higher in years with higher total phosphorus concentrations, and nutrients were an important

predictor of phytoplankton community composition over time (Palmer and Winter, unpublished data).

2.2 Water Quality Assessment of Ten Lake Superior Embayments, Spring 1983

In the spring of 1983, ten embayments were investigated in Lake Superior, one of which included Thunder Bay (Simpson 1987). Thirty-two stations within the whole of Thunder Bay were sampled, with the majority located on the western shore. Total phosphorus concentrations were highest and exceeded the TP-PWQO in the nearshore area of the McIntyre River (26 µg/L), Neebing River (34 µg/L), and Kaministiquia River (39 µg/L); concentrations gradually declined into the off-shore waters. The remainder of the stations in the whole of the Bay had TP concentrations that ranged from 5 to 18 µg/L.

2.3 Thunder Bay Nearshore Water Quality Assessment

In 1983, nearshore water quality study was conducted to define the nature and extent of water quality impairment in Thunder Bay (Anderson 1986). Sixty stations were sampled and it was determined that the mean TP concentration was 15 µg/L ± 18 SD. Twenty-five percent of the stations sampled had an average TP concentration > 20 µg/L; the provincial guideline required to avoid nuisance concentrations of algae. Most of these sites of concern were located in the Kaministiquia River delta and near Bare Point. No nuisance algae growths were identified at these sites.

2.4 Water and Sediment Quality in the Kaministiquia River Delta and Nearshore Area of Lake Superior

Water quality at stations located in the Kaministiquia delta and offshore waters were measured in the late spring and summer of 1985 and 1986 (Boyd 1990). Generally it was determined that the TP-PWQO (20 µg/L) was exceeded in the delta area, with mean concentrations ranging from 36 to 100 µg/L at the depth of maximum turbidity, and 12.5 to 31 µg/L at the depth of minimum turbidity. However, it was noted that nuisance algae was not an issue in this study area, stating the oligotrophic nature of the receiving water ensures the elevated concentrations are diluted to less than the PWQO.

2.5 Great Lakes Reconnaissance Survey

As part of the Great Lakes Nearshore Monitoring and Assessment Program, data was collected on Lake Superior under the Great Lakes Reconnaissance Surveys and the Great Lakes Nearshore Index Station Network (Richman 2004). Eleven stations, located mainly in the delta area of the Kaministiquia River, the north end of the harbour and bare point, and a station at the Welcome Island were sampled in 1999. Results showed the highest levels of TP were detected at the mouths of the Kaministiquia and Mission Rivers (ranging from 32 to 72 µg/L over three surveys).

2.6 Assessment of Total Phosphorus and Chlorophyll in Thunder Bay, 2005

In 2005, the Ministry of the Environment undertook a study measuring TP and chlorophyll-*a* concentrations as water quality indicators of trophic status (Benoit *et al*. 2012). The survey was intended as a screening level survey to determine the need for a more direct and quantitative

evaluation of plankton populations to assess the degradation of plankton BUI. Stations were located in the Kaministiquia delta, harbour area, and offshore towards the Welcome Island. More details of this study are provided in section 4.1.

2.7 Great Lakes Nearshore Index Station Network

The Ministry of Environment and Climate Change undertakes a comprehensive survey of eighteen stations on Lake Superior (including the St. Marys River) under the Great Lakes Nearshore Index Station Network (MOECC, unpublished). This program was implemented in 1999 and the surveys are conducted every six years (2005 and 2011). Phyto/zooplankton samples are collected, along with water, sediment, and benthos samples.

2.7.1 Plankton Assessment

The Freshwater Ecosystem Research section of the Great Lakes Laboratory for Fisheries and Aquatic Sciences at Fisheries and Oceans Canada has summarized the available plankton data from Thunder Bay and has reported separately (Currie *et al*. 2015). Since data on plankton communities within the AOC are very limited, data sets from the general area of Thunder Bay were assessed and presented. The Ministry of the Environment and Climate Change provided plankton samples from index stations 283 (Flatland Island), 284 (Welcome Island), and 285 (Sturgeon Bay) collected in each season over 3 years (1999, 2005, and 2011 in spring, summer, and fall). Additional samples were provided to Fisheries and Oceans Canada by Environment Canada, Ontario Ministry of Natural Resources and Forestry, and the United States Geological Survey.

3.0 REMEDIATION AND DELISTING

3.1 Guidelines

In 1991, the International Joint Commission (IJC) provided listing and delisting guidelines to serve as indicators for use impairments in the Great Lakes, as well as to assist in identifying new AOCs, and reviewing all stages of remedial action plans (RAPs). The listing/delisting guidelines for the '*Degradation of Phytoplankton and Zooplankton Populations'* beneficial use impairment (BUI) reads as follows:

Listing – when phytoplankton or zooplankton community structure significantly diverges from unimpacted control sites of comparable physical and chemical characteristics. In addition, this use will be considered impaired when relevant, field- validated, phytoplankton or zooplankton bioassays (e.g. *Ceriodaphnia*; algal fractionation bioassays) with appropriate quality assurance/quality controls confirm toxicity in ambient waters.

Delisting – when phytoplankton and zooplankton community structure does not significantly diverge from unimpacted control sites of comparable physical and chemical characteristics. Further, in the absence of community structure data, this use will be considered restored when phytoplankton and zooplankton bioassays confirm no significant toxicity in ambient waters.

3.2 Delisting Criteria

Prior to the designation of this BUI as impaired, the Great Lakes Water Quality Board prepared a report on the water quality of the Great Lakes for the IJC (Great Lakes Water Quality Board 1987). Appendix A of the report provided a summary of the environmental assessment of the area and the RAP development process for each AOC. The area of focus in Thunder Bay was the Kaministiquia River and the following was provided with regard to the plankton BUI:

> *"Recent assessments of nutrient concentrations in Thunder Bay indicate that although total phosphorus concentrations remain high in the lower Kaministikwia River, eutrophication is not a problem. Trend analyses based on weekly sampling of intake waters from the Bare Point pumping station in the northern part of Thunder Bay harbour showed no significant increases in total phosphorus or total Kjeldahl nitrogen from 1980-1984 and, as expected, no apparent increases in phytoplankton biomass. In general, phytoplankton production in Thunder Bay waters is low and does not represent a nuisance condition."*

The status of the plankton BUI in Thunder Bay was deemed impaired in 1991, with the condition of the plankton populations in Thunder Bay "…assumed to be degraded in the Kaministiquia River and in the Harbour, within the breakwall" (Thunder Bay Remedial Action Plan Team 1991). Based on the documented impairment of both water quality and benthic communities, it was assumed that the plankton populations were also impaired. The accidental introduction of exotics, such as the spiny water flea (*Bythotrephes cederstroemi*), was also of concern; the predacious exotic zooplankton was introduced in the harbour in 1988 (Thunder Bay Remedial Action Plan Team 1991).

In the Stage 2 RAP (Thunder Bay Remedial Action Plan Team 2004), the status of the plankton BUI continued to be deemed impaired. Specifically, it was stated that populations were assumed to be degraded in the vicinity of industrial outfalls; however, there were no assessment studies conducted. It was recognized in the Stage 2 RAP (Thunder Bay Remedial Action Plan Team 2004) that process effluent from Bowater, the pulp and paper mill on the Kaministiquia River, was not acutely toxic to *Ceriodaphnia*. In addition, secondary treatment at Abitibi (at the mouth of the Mission River) was implemented, and effluent toxicity decreased (Thunder Bay Remedial Action Plan Team 2004).

The status of the BUI, as well as the key actions completed and remaining, were outlined in 2010 by the provincial and federal governments (EC/MOE 2010). The status of the 'degradation of phytoplankton and zooplankton populations' was changed to 'requires further assessment' since it was acknowledged that the BUI was assumed to be impaired, but not assessed prior to that determination. As such, there are no formal delisting criteria for the degradation of plankton BUI given the current status.

3.3 Remedial Strategies

The intention of the Stage 2 RAP report (2004) was to outline remedial strategies to restore the impaired beneficial uses for the Thunder Bay AOC. Since there were no studies to verify the

assumption of degradation, the Stage 2 report recommended that studies be carried out to obtain a baseline measurement of the plankton communities, as well as to collect any information necessary to determine suitable remediation measures. Once the baseline and investigative studies were completed, then appropriate delisting criteria, a remediation strategy, and a monitoring program would be developed under the three Management Actions in the RAP report (Stage 2 RAP 2004).

The alternative strategy in the Stage 2 RAP report (2004) was to gather the opinion of an expert panel to determine if the studies verify the impairment. If no impairment was apparent, then the BUI status would be changed accordingly.

Despite the recommendations made in the Stage 2 RAP, plankton studies were not completed. In the time that had lapsed since that recommendation, the issues that were originally identified as causing the impairment had improved. It was discussed at the 2014 Remedial Action Plan Workshop that, where insufficient data exists, it must be decided whether the cost of collecting and analyzing the data is justified given the implications of the BUI. In light of the current priorities for the Thunder Bay AOC, a full plankton survey could not be justified at this point. These factors, in addition to the support shown for a pragmatic lines of evidence approach at the 2014 Remedial Action Plan Implementation Workshop (section 1.1.3), prompted this rationale document which reviews the lines of evidence that directly and indirectly relate to the plankton BUI. This approach to determine the current status of the plankton BUI was supported by the Remedial Action Plan Team.

4.0 LINES OF EVIDENCE

Ideally, the degradation of phytoplankton and zooplankton populations BUI would have been assessed using plankton data collected prior to the status determination, and at several time intervals afterwards. Adequate replicates of plankton samples would have been collected on a temporal (seasonal) basis from representative sampling locations within and outside the AOC. Given that this did not occur, this assessment report will use the same reasoning that was used to list the BUI to both determine the current status of the BUI and the progress towards delisting. A lines of evidence approach can be used to indirectly assess or infer the health of the plankton population in the most heavily impacted areas of the Thunder Bay AOC.

4.1 Top-Down and Bottom-Up Approach

4.1.1 Introduction

The top-down and bottom-up approach was introduced at the 2004 COA Monitoring Workshop. The basis of the approach was that the plankton trophic level would be assumed to be healthy and sustainable if the trophic levels above (predators; fish community health) and below (plankton food; water quality indicators) were healthy.

It is recognized that trophic interactions are very complex, and that the top-down and bottom-up approach offers only a high-level generalized view of the status of the target trophic level, in this case plankton. However, this pragmatic recommendation, generated from the workshop, served as a screening level assessment that would be used to determine further action, if necessary.

4.1.2 Bottom-Up

In 2005, the MOE measured total phosphorus and chlorophyll-*a* (as well as other water quality parameters) in the nearshore area of Thunder Bay in order to provide a 'bottom-up' assessment of plankton in the AOC (Benoit *et al*. 2012). The approach taken in this study, herein referred to as the TP/chlorophyll study, was supported by studies (Shuter and Ing 1997, Stemberger *et al*. 2001) were it has been shown that chemical and physical indicators, such as chlorophyll concentrations and total phosphorus, can serve as sensitive indicators of biological status.

The stations examined in the 2005 TP/chlorophyll study were separated into three main blocks: the Kaministiquia delta and river (including Mission and McKellar Rivers); the Harbour; and the off-shore areas. As expected, concentrations of measured water quality parameters were highest in the nearshore area, especially in the Kaministiquia delta, and decreased to offshore station locations. The concentrations of TP were highest, and elevated above the TP-PWQO, at the convergence in the Kaministiquia River and at the mouths of the Kaministiquia, McKellar, and Mission Rivers, with average concentrations ranging from 38.2 to 57.3 µg/L. The median concentrations of chlorophyll-*a* were low, ranging from 1.1 to 2.7 µg/L, and representative of a typical oligotrophic system.

The consistently low concentrations of chlorophyll-*a* at the stations sampled in this study suggest that the algal populations were likely limited by light and temperature, rather than TP (Hopkins 1986); Benoit *et al*. (2012) further supported this conclusion by use of a biomass-based trophic state index (TSI). Large variations in TP and chlorophyll relationships do exist and are associated with regional, biogeographical, morphometrical, and physico-chemical features of the body of water (Stemberger *et al*. 2001). The TSI suggested that the potential prevalence of phosphorus bond to particulate matter in the river water did not influence chlorophyll concentrations. The TSI for offshore stations was consistent with the oligotrophic nature of the open lake.

Overall it was determined that: (1) the elevated TP concentrations at some sites were not indicative of negative effects; (2) chlorophyll-*a* concentrations do not suggest high algal biomass; and (3) the TSI (as determined by the interplay of TP, chlorophyll, and secchi depth) showed that other parameters such as DOC and turbidity/suspended solids (as inferred by conductivity) were somewhat responsible for the shallow water column transparency at the more impacted nearshore stations. Benoit *et al*. (2012) concluded that the TP-chlorophyll-*a* relationship suggested that the AOC is not phosphorus limited, and that the overall chlorophyll-*a* concentrations would not likely result in undesirable algae. The deltic area water chemistry differed from the open water chemistry; however, that was simply due to the urban and industrialized characteristics of the waterfront.

4.1.3 Top-Down

Assessments of more recent fish community data in Thunder Bay have been used to fulfill the 'top-down' portion of the overall top-down, bottom-up approach (Foster 2012, Marshall 2015).

Generally, the status of the Thunder Bay fish community is evaluated against the BUI delisting criteria which states that: fish populations will no longer be impaired when the species composition and relative abundance of the fish community within the AOC is similar to the nearshore (0-80 m deep) community located adjacent to the AOC for three consecutive years. Further to this, there are specific requirements (age, length, maximum mortality rates, etc.) of self-sustaining populations of native species, such as Lake Trout, Lake Whitefish, Lake Sturgeon, Walleye, and Brook Trout.

Marshall (2015) assessed the status of fish populations, and their habitat, using data collected from the MNRF's Fish Community Index Netting program, spanning from 2009-2014. The assessment determined that although the fish community has changed substantially in comparison to historical observations, Thunder Bay supports a more diverse fish community than adjacent areas. In a separate review of a number of studies, Foster (2012) confirmed fifty-five species in an area that included the Thunder Bay North Harbour, Current River, Thunder Bay Harbour, and Thunder Bay as a whole. The catch per unit effort of fish was the same within and outside the AOC; however differences were noted in the contribution of individual species (Marshall 2015). The increased abundance inside the AOC, and the variation in species abundance was likely due to differences in physical habitat.

There were several reasons cited to account for the changes to the populations and community over time, including habitat modification due to industrial, residential, and recreational development; commercial and recreational over-exploitation; introduction of exotic species; and dredging, channelization, and the release of pollutants. Remedial and restoration activities, and monitoring initiatives that have been implemented to address these issues and the Stage 2 RAP recommendations (Marshall 2015).

The abundance and biomass of native and non-native planktivorous fish, specifically, in the Thunder Bay AOC mirrors the results from a lake-wide study conducted by the USGS in 2014 (Vinson *et al*. 2014). Measurements of these two indicators have shown a lake-wide decline at all trophic levels of fish. Preliminary results from the Ministry of Natural Resources and Forestry Community Index Netting Survey (2009-2014) showed the highest catch per unit effort to be in 2012, with a decrease in the following two years. It was noted that 2012 was a warm summer, which lead to an increased success in fish capture; by comparison 2013 and 2014 had much cooler sampling seasons. Despite low abundance and biomass, other indicators such as periodic recruitment and survival suggested that the populations in the AOC are healthy (E. Berglund, personal communication 2015).

4.1.4 Conclusion

The top-down/bottom-up approach was not supported by all technical experts at the 2010 COA Expert Workshop. However, given that there was no generally accepted standard for

establishing plankton restoration objectives at the time, especially in dynamic areas such as tributary mouths, the Remedial Action Plan Team supported the implementation of this approach. The intention behind the 2005 chlorophyll and TP study was to take a pragmatic approach to the issue and to conduct a screening level assessment, which could then be used to determine whether additional sampling efforts were warranted.

From the perspective of the bottom-up, the TP-chlorophyll-*a* relationship has shown that the study area is not phosphorus limited, and that chlorophyll-*a* concentrations are not likely to result in undesirable algae; temperature and light are thought to be the limiting factors. In addition, there is little evidence that of nutrient-driven eutrophication in the AOC, and the offshore areas remain oligotrophic.

From the ‘top-down’, current data suggested that the Thunder Bay AOC supports a more diverse fish community than the adjacent areas. It has been noted that the biomass and abundance of fish within the AOC has decreased over recent years; however, this trend is also being observed lakewide. In general, pelagic and transient fish prefer the open lake waters where the temperatures are cooler, and as such, their presence in the nearshore waters of the AOC suggests habitable conditions and an adequate food source.

Using the combination of data collected from the bottom-up and top-down approaches, it was determined that there was little need to continue the assessment of the degradation of plankton and zooplankton populations BUI.

4.2 Effluent Monitoring and Effluent Limits Regulations

The Municipal-Industrial Strategy for Abatement (MISA) was the backbone of nine Effluent Monitoring and Effluent Limit Regulations (EMEL) (one for each industrial sector type) developed under Ontario’s *Environmental Protection Act* in the early 1990s. The legislation regulates the industrial discharges of contaminants into surface waters through setting loading limitations for certain toxic substances, parameter and lethality limits, and monitoring schedules.

Within the areas originally identified as potentially being impacted (Kaministiquia River and the inner Harbour) there are two industry sectors that fall under EMEL: pulp and paper sector, and electric power generation sector. The effluent monitoring and effluent limits for the pulp and paper sector are regulated under Ontario Regulation 760/93, and in this case include(d): Resolute Forest Products (formerly Bowater Pulp and Paper Canada Inc.), Abitibi-Consolidated Inc., Fort William Division (now closed), and Superior Fine Papers (formerly Cascades Fine Paper Group Inc. – now closed). The electric power generation sector effluent monitoring and effluent limits are regulated under Ontario Regulation 215/95 and captures Ontario Power Generation, Thunder Bay Thermal Generating Station. The focus of this discussion will be on the active facilities: Resolute Forest Products and Ontario Power Generation.

4.2.1 Toxicity Testing

According to the effluent monitoring and effluent limit regulations, the discharger shall control the quality of the monitoring stream from the plant to ensure that the mortality that may result from acute toxicity tests conducted on *Daphnia magna* and Rainbow Trout does not exceed 50% in 100% effluent. Acute toxicity tests are conducted monthly, until which time twelve consecutive passes (test not exceeding 50% mortality) is achieved; at this point acute toxicity monitoring is conducted quarterly. In this assessment, data from all effluent control pipes were consolidated on a monthly basis. Therefore, if a violation (fail) occurred at only one pipe, a violation was still noted for that month.

Chronic toxicity tests are conducted semi-annually on *Pimephales promelas* (fathead minnow), the zooplankton *Ceriodaphnia dubia*, and the phytoplankton *Selenastrum capricornutum*. Growth inhibition is used as the measurement endpoint in the 7-day Fathead Minnow tests, reproduction inhibition and survivability is used in the 7-day *C. dubia* test, and growth inhibition is used as the endpoint in the 72-hr *S. capricornutum* toxicity test. The potential for impairment is demonstrated by the IC25, which is defined as the concentration (% effluent) which causes a 25% inhibition of a specified endpoint. Chronic toxicity tests are only conducted when twelve consecutive acute toxicity testing passes have been achieved.

4.2.1.1 Resolute Forest Products

Resolute Forest Products (and former companies) have had minimal acute toxicity exceedences for *Daphnia magna* and Rainbow Trout for the sampling period of 2002 to 2015 (not all data before that time was readily available) (Figure 1A and 1B). In the past three years there have been no toxicity failures in any of the monthly effluent samples. Acute toxicity failures in previous years have been intermittent and generally have had a specific reason (e.g., shutdown) (M. Holenstein, personal communication 2015). The Environmental Officer at the Ministry of the Environment and Climate Change is advised of all adverse test results and conducts an investigative follow-up.

At certain times, effluent from the combined-mill outfall has posed a potential for chronic impairment to plankton. While the biannual results prove to be variable since 1997, the last 1.5 years have shown very minimal to no risk of sub-lethal effects to plankton populations (Figure 2A and 2B). There are no measureable chronic effects (growth) observed with *Pimephales promelas* (fathead minnows) exposed to 100% effluent in the laboratory (Figure 2C). The Aquatic Toxicology Unit with the Laboratory Services Branch at the Ontario Ministry of the Environment and Climate Change will be reviewing the chronic toxicity data in the near future.

Although the end-of-pipe effluent has been shown to have the potential to cause chronic toxicity to *C. dubia*, it is noted that the Kaministiquia River has an assimilative capacity that is capable of diluting the effluent to concentrations that do not inhibit growth or reproduction (as measured by IC25) in the laboratory. XCG Consultants Ltd. (2005) ran a CORMIX model showed that at average flow rates, the mill effluent was diluted to 7% of the initial concentration in the near-field (13.5 m downstream of diffuser) and 4% at

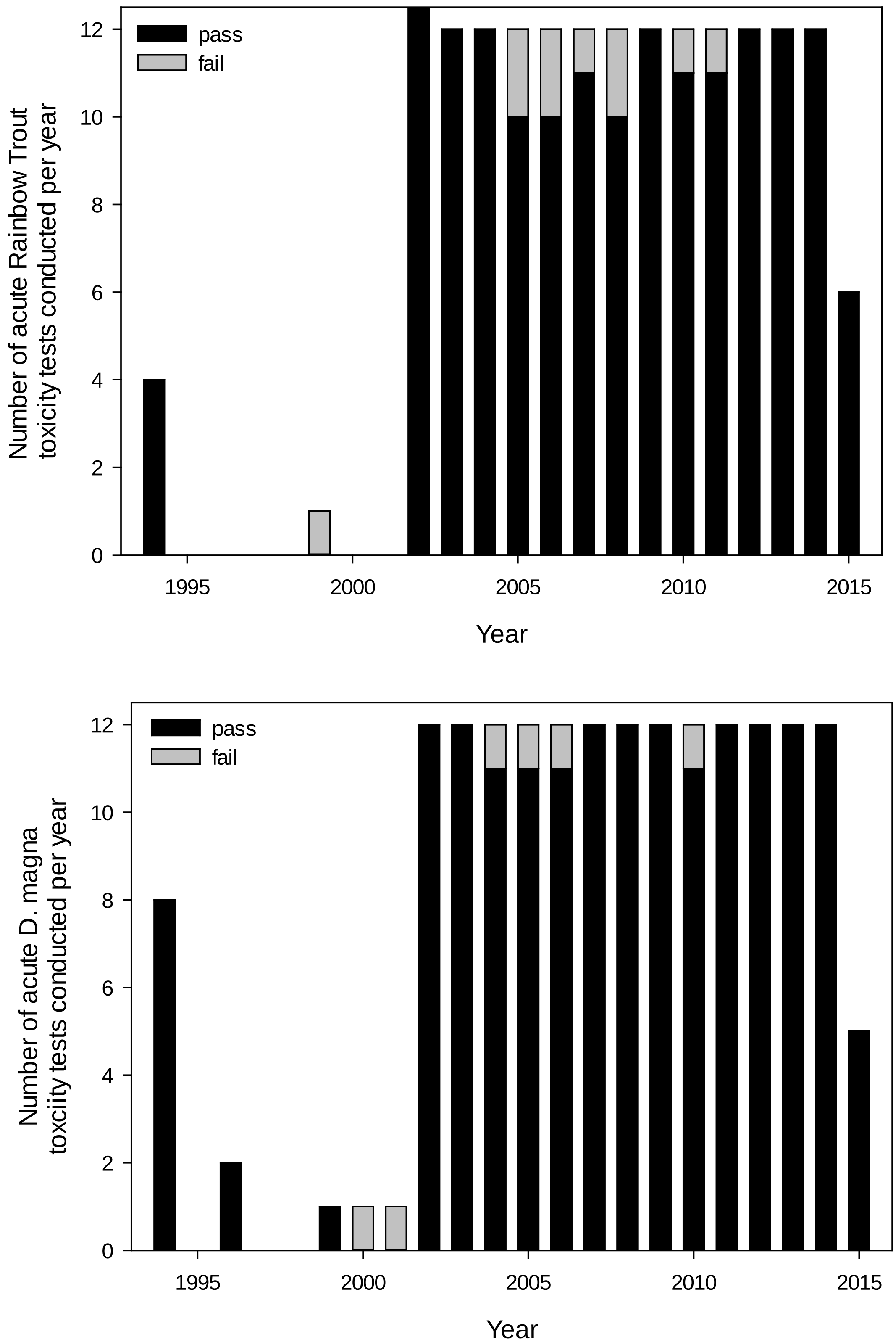

Figure 1. Resolute Forest Products acute toxicity test results for A) Rainbow Trout and B) *Daphnia magna* (1994 – 2015).

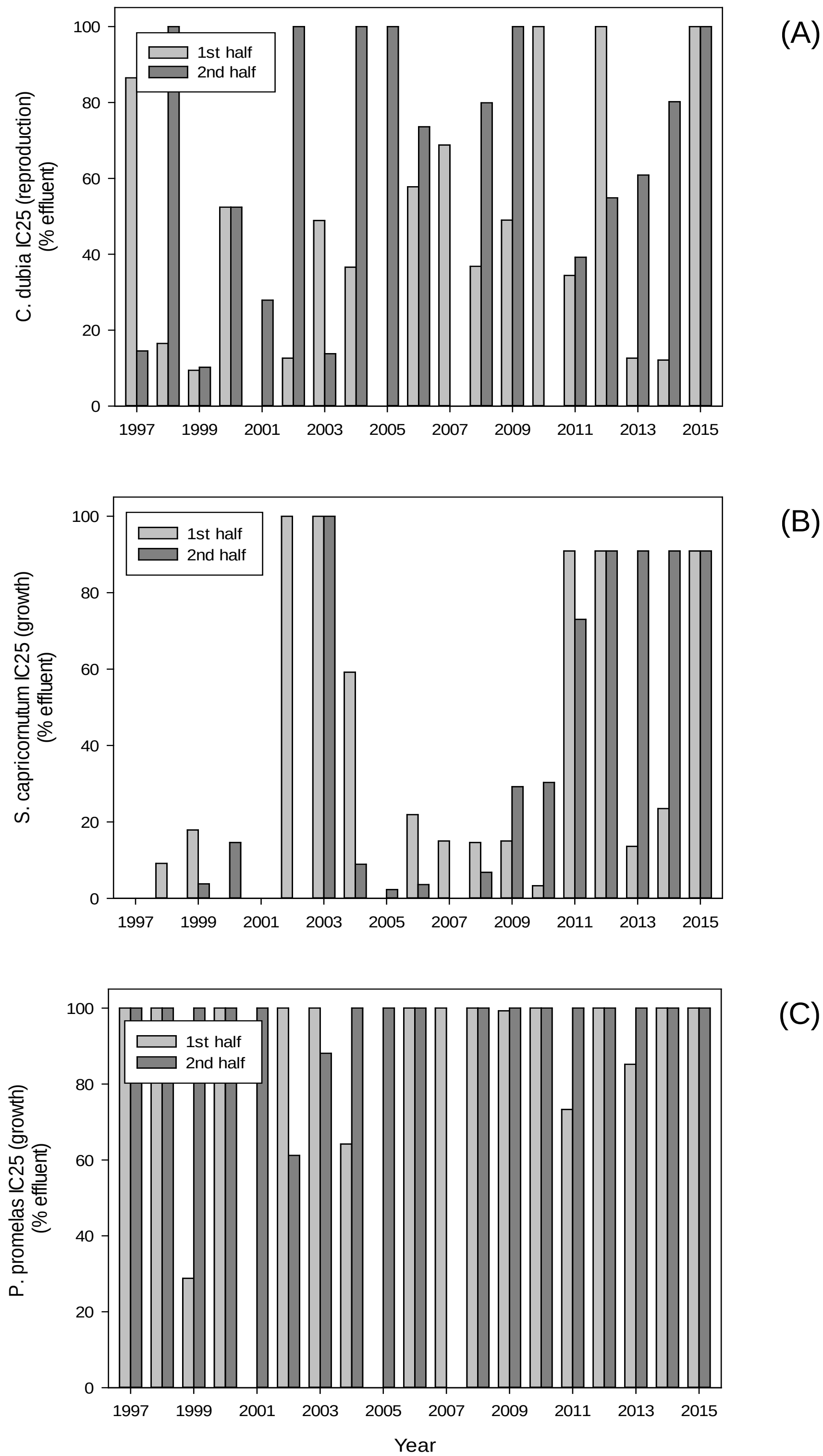

Figure 2. Resolute Forest Products chronic toxicity test results for A) *Ceriodapnia dubia*, B) *Selenastrum capricornutum*, and C) *Pimephales promelas* (1997 – 2015).

the river mouth. As such, based on available toxicity data (IC25 and confidence intervals) from 1997 to present day, it would be expected that there would be no inhibition of reproduction to *C. dubia* in the near-field and beyond. The effluent has been proven to be more toxic to *S. capricornutum* at times; however the IC25 has remained above 7% effluent since the latter half of 2010.

4.2.1.2 Ontario Power Generation, Thunder Bay Thermal Generating Station

Two test control points are sampled at OPG to collect effluent for the assessment of acute and chronic toxicity under EMEL regulation: the ash transport water treatment plant (ATWTP - 200) and the oily water separator (OWS - 1100).

Acute toxicity tests on *Daphnia magna* and Rainbow Trout have been conducted on a quarterly basis since 2007. Toxicity failures were noted in the early 1990s; however there have been no violations reported in the past decade (data was scarce prior to 2006).

In the past decade there have been minimal incidences of chronic impairment to the zooplankton *Ceriodaphnia dubia* and fathead minnows (*Pimephales promelas*) when exposed to effluent from the two streams (Figure 3A and 3B). The chronic impairments could not be explained; however where impairment was evident, there was no impact on survival of the exposed organisms.

4.2.2 Loadings

Loading limits for each industrial sector were originally established in the respective EMEL regulation. As per the regulation, the limits can be amended based on the reference production rate. The company reports quarterly through the Ministry of the Environment Wastewater System (MEWS) on specific parameters at different control points. In addition, an Environmental Compliance Approval may establish stricter, receiver-based discharge and loading limits; however the reporting requirements differ from the EMEL regulations.

4.2.2.1 Resolute Forest Products

Resolute Forest Products (and former companies) is (was) required to report on loading values for adsorbable organic halides (AOX), toluene, biological oxygen demand (BOD_5), flow, phenol, total suspended solids (TSS), and chloroform. The company also reported on dioxins and furans until 2006. Figures 4A, 4B, and 4C show that generally the annual average loadings have decreased over the past decade as a result of closures of certain components of the mill, namely a number of paper machines, and one of the market kraft pulp mills. There have been no monthly violations of the effluent loading limits since 2005.

4.2.2.2 Ontario Power Generation, Thunder Bay Thermal Generating Station

The Thunder Bay Generating Station is required, under the EMEL regulation, to report on loading values for aluminum (Al), iron (Fe), TSS, solvent extractables (SE), and flow. Figure 5 shows the annual average of loading levels of the reportable

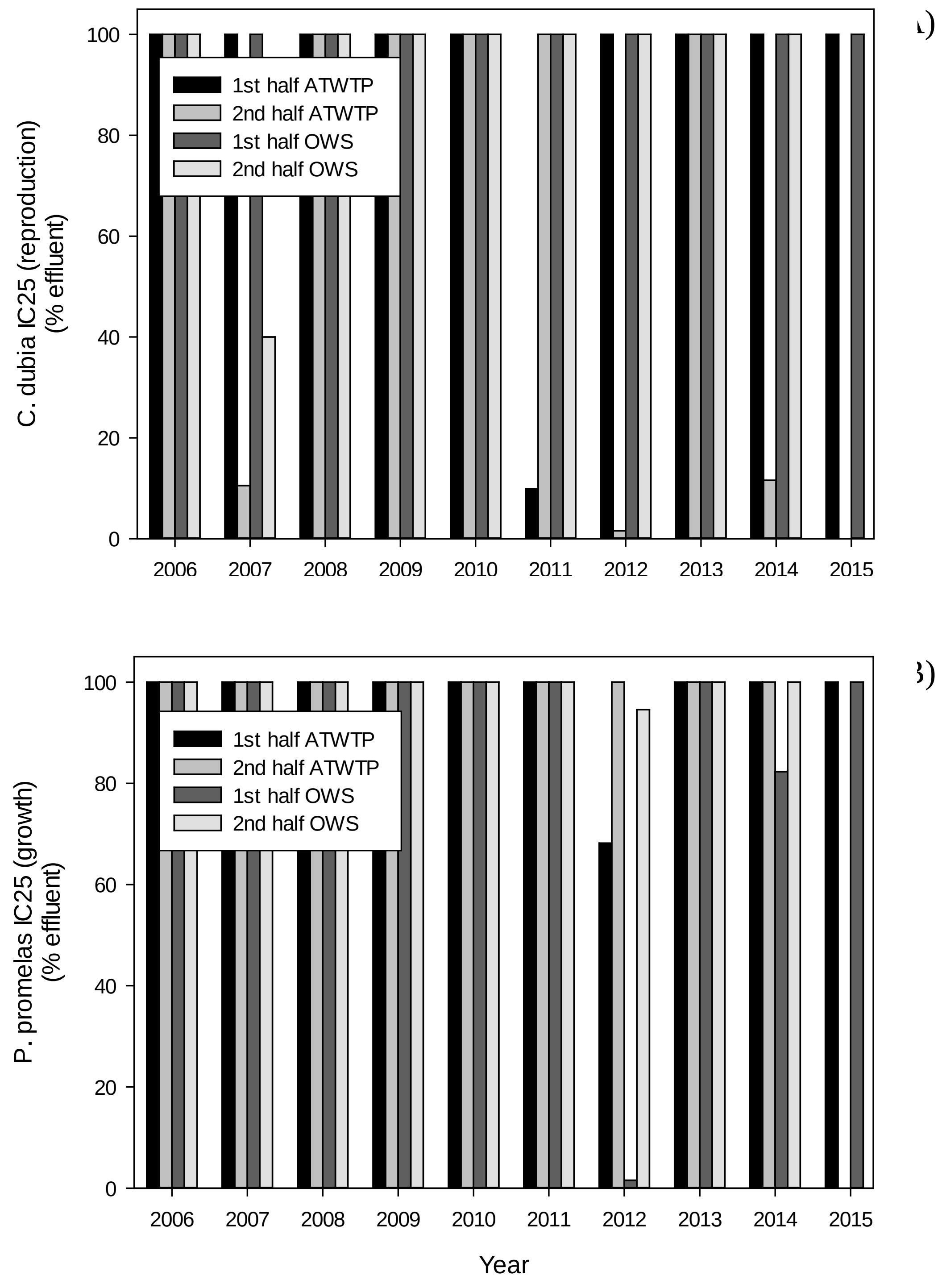

Figure 3. Ontario Power Generation, Thunder Bay Thermal Generating Station acute toxicity test results for A) *Ceriodaphnia dubia* and B) *Pimephales promelas* (2006 – 2015).

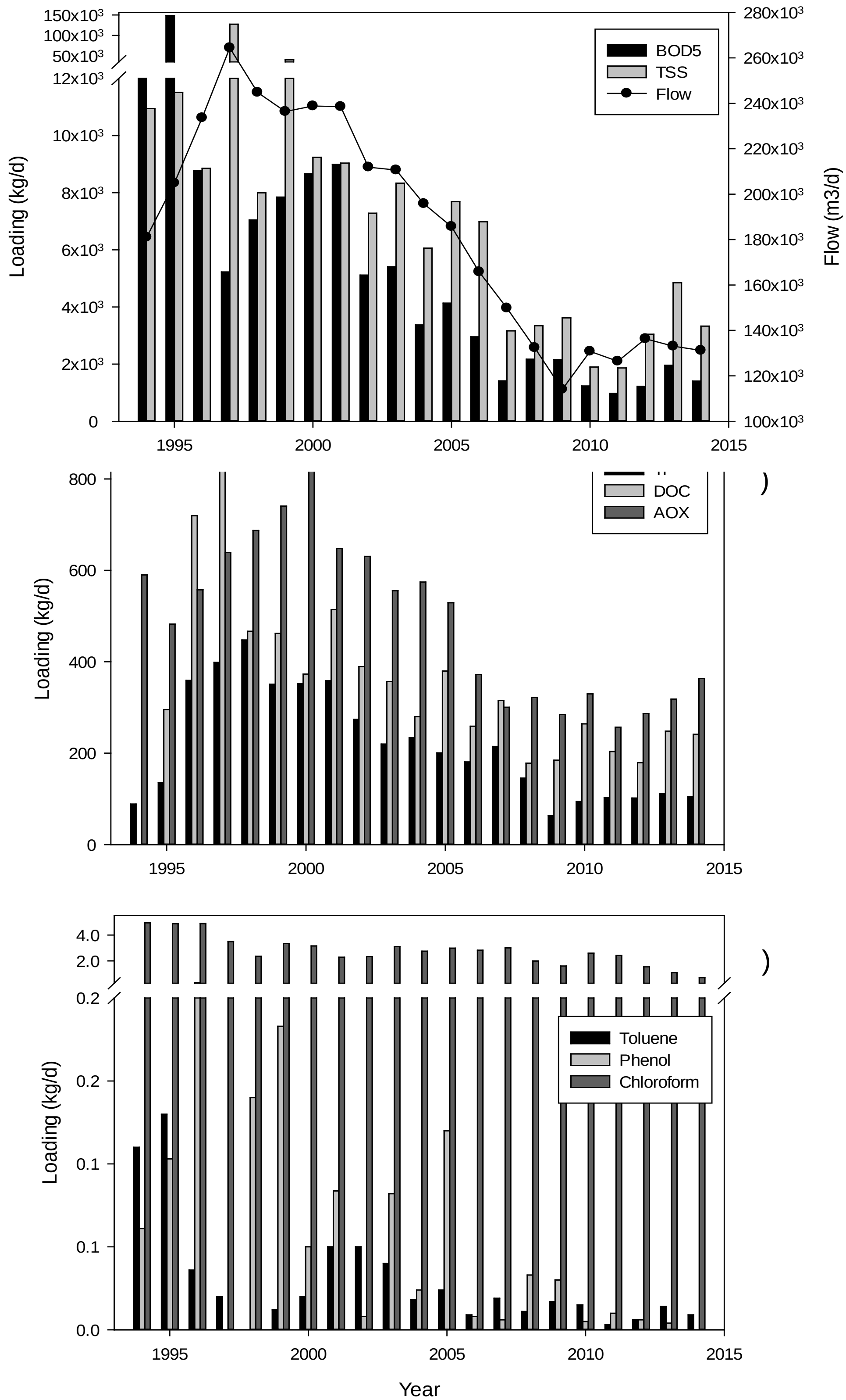
BOD5
TSS
Flow
Loading (kg/d)
Flow (m3/d)
DOC
AOX
Toluene
Phenol
Chloroform
Year

Figure 4. Loading levels (annual average) of regulated parameters (A) BOD_5, TSS, flow; B) TP, DOC, AOX; and C) toluene, phenol, and chloroform) at Resolute Forest Products (1994-2015).

parameters from a plant level. There has been a decrease in the loadings of reportable parameters (from a plant level) since the mid-1990s; a trend that can be mainly attributed to decreased production rates over the past decade. There have been no monthly violations of the effluent loading limits since 2006.

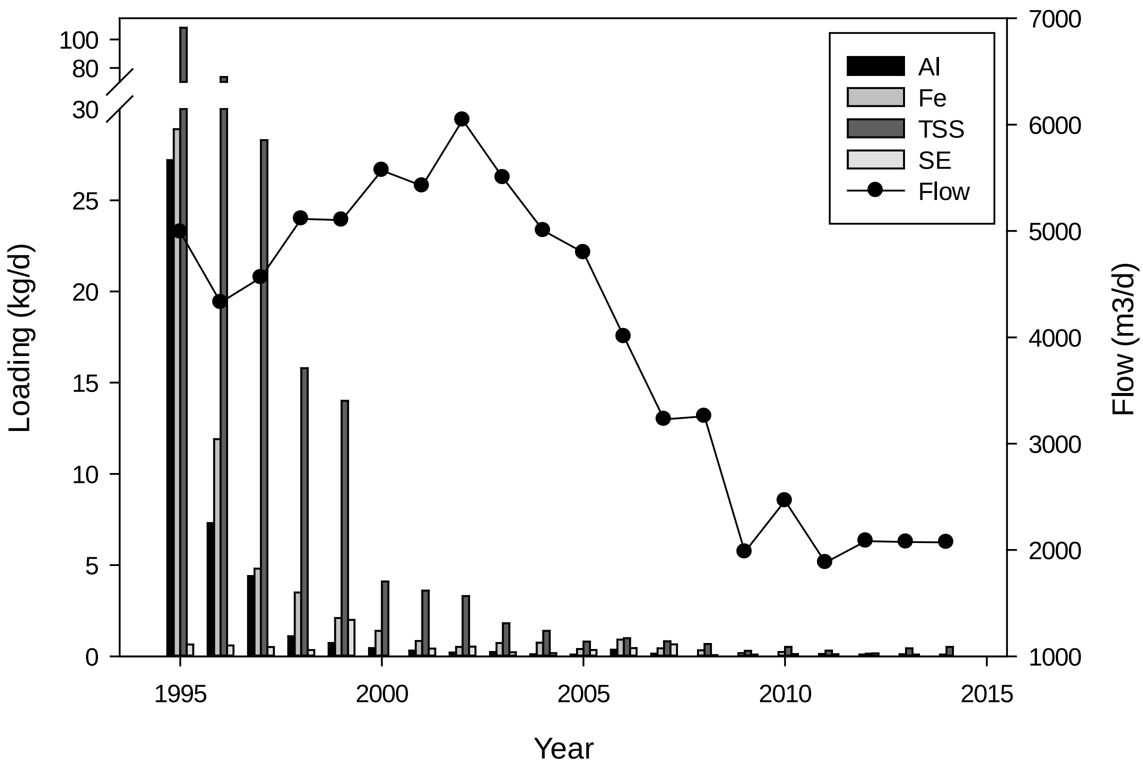

Figure 5. Loading levels (annual average) of regulated parameters Al, Fe, TSS, SE, and flow at Ontario Power Generation, Thunder Bay Thermal Generating Station (1994-2015).

4.2.3 Treatment Upgrades and Process Changes

4.2.3.1 Resolute Forest Products

The operation of Resolute Forest Products has changed substantially since the 1990s (Table 1). In regards to effluent quality, the most significant treatment changes has been: the installation of secondary treatment (kraft mill in 1993 and newsprint mill in 1995), the switch to elemental chlorine free bleaching (100% chlorine dioxide) in

1994, and the elimination of the sulphite mill, with the replacement of the thermo-mechanical pulp mill, which is a cleaner technology.

Operational declines in the past decade, namely the reduction to one paper machine and one market kraft pulp mill, has also been a major contributor to the improved effluent in terms of both quality and quantity.

Table 1. Changes to Resolute Forest Product, and former companies, mill components (1990-2014).

Mill Component	1990s	2000-2009	2010-2014
Paper machine	4 (no. 1 - 4)[1,2] @ 1300 mt/day	3 (no. 3 – 5)[3] @1500 mt/day	1 (no. 5) @ 615 mt/day
Market Kraft pulp mill	2 (A and B) @ 1600 mt/day	2 (A and B)[4] @ 1600 mt/day	1 (B) @1000 mt/day
Recycle plant	1[5]	1	0[6]
Thermo-mechanical pulp mill	1[7]	1	1

[1] no. 1 and 2 shut down in 1991
[2] no. 5 started in 1991
[3] no. 3 and 4 shut down in 2003 and 2009, respectively
[4] mill A shut down in 2006
[5] started in 1992
[6] shut down in 2011
[7] started in 1991

4.2.3.2 Ontario Power Generation, Thunder Bay Thermal Generating Station

Current knowledge suggests that there have been no treatment upgrades, or none of significance, to either the ash transport water treatment plant or the oily water separator. The most significant operational change to the plant was in 2014 when they ceased burning coal.

4.3 Thunder Bay Water Pollution Control Plant Treatment Upgrades

The Atlantic Avenue Water Pollution Control Plant (WPCP) was expanded and retrofitted in 2005 to become a secondary sewage treatment plant. The upgrade, which was a part of the City's 1999 Pollution Prevention and Control Plan, included secondary treatment, phosphorus removal, sludge digestion and dewatering, and a nitrification process to eliminate wastewater (City of Thunder Bay 2015). As shown in Table 2, the upgrade to the plant substantially improved the quality of the effluent, with the biochemical oxygen demand ($CBOD_5$) and total suspended solids (TSS) decreasing by more than an order of magnitude. The 2015 annual

average (based on data from the first half of the year) concentrations of $CBOD_5$, TSS, and TP were all below the effluent objectives outlined in the WPCP's Environmental Compliance Approval (Table 2). Effluent objectives are set for total ammonia (NH_3); however no effluent compliance limits are set for this parameter. The WPCP reports on TKN, which decreased from an annual average of 21.3 mg/L in 2004 to 3.5 mg/L in 2015.

Table 2. Environmental Compliance Approval effluent objectives and limits, and effluent concentrations pre- and post-treatment upgrade for the Atlantic Avenue Water Pollution Control Plant.

Parameter	Effluent Objectives[1] (mg/L)	Effluent Limits[2] (mg/L)	Pre-upgrade (2004)[3] (mg/L)	2015 (1st half)[3] (mg/L)
$CBOD_5$	15.0	25.0	74.2	7.8
TSS	15.0	25.0	39.9	8.7
TP	0.5	1.0	0.96	0.4

[1] the Owner shall use the best efforts to design, construct and operate the Works with the objective that the concentrations do not exceed the specified value.
[2] the Owner shall operate and maintain the Works such that the concentrations specified are not exceeded.
[3] annual average

4.4 Industrial Closures

Since the designation of the AOC, there have been many changes to the industrial landscape of the Kaministiquia River and inner Harbour. In the past, there were several significant industrial point sources of contaminants and BOD loads into the receiving waters of this area of interest. The closure of many of these industries has contributed to the improvement of the surface water and sediment in the lower Kaministiquia River and inner Harbour (George 2012, Clerk *et al*. 2012). The most significant point source dischargers on the Kaministiquia River that have ceased operation are: Riverside Grain Products Inc. (formerly Ogilvie Mills Ltd.), Arclin Canada Ltd. (formerly Reichhold Limited), and Abitibi Consolidated Inc. - Fort William Division (located at the mouth of the Mission River). Within the inner Harbour, Northern Wood Preservers Inc., and Superior Fine Papers have closed.

Riverside Grain Products Inc. (formerly Ogilvie Mills Ltd.), was located on the shore of the Kaministiquia River, and produced wheat gluten and starch. Under the ownership of Ogilvie, the mill operated from 1912 to 1996 (Turner and Francesca) and discharged via a bank outfall to the river. Riverside Grain Products Inc. reopened the mill in 1998 and operated until its closure in 2000 (Turner and Francesca). The Certificate of Approval for the mill (dated 1985) allowed for a discharge of 900 kg of BOD_5/day. A study of the water quality of the lower Kaministiquia River in 1986 (Klose 1988) showed the effluent loads from the mill to have a high levels of BOD (478 mg/L), suspended solids (1310 mg/L), and total phosphorus (117 mg/L). Additionally, three 24-hour composites of effluent was collected and analyzed for over 120

organic and inorganic parameters. Analysis results showed that 27 parameters exceeded the detection limits, and of that, 11 parameters exceeded the applicable Ontario Provincial Water Quality Objectives. The 11 parameters that were noted for further analysis included: heptachlor (12 - 42 ng/L); pp-DDE (120 ng/L); pp-DDD (25 ng/L); endosulfan II (58 ng/L); dieldrin (4 - 46 ng/L); endrin (22 ng/L); dehydroabietic acid (28 µg/L); iron (1.50 - 4.10 mg/L); manganese (0.33 – 0.71 mg/L); copper (0.15 – 0.34 mg/L); and zinc (0.36 – 1.10 mg/L). According to 1986 measurements, the average effluent flow rate of the grain mill (0.008 m^3/s) was three orders of magnitude less than the upstream pulp and paper mill and the WPCP; however the levels of BOD_5, suspended solids, and TP were significantly higher.

Arclin Canada Ltd. produced adhesive resins that were used mainly in the manufacturing of particleboard and oriented strandboard. Formerly Reichhold Limited, Neste Canada Inc. (1999-2001), and Dynea Canada Ltd. (2001-2007), the plant ceased operation in October 2009. Although Reichhold was no longer discharging directly into the Kaministiquia River when the AOCs were formed, it was recognized as one of the significant point sources in the 1986 study conducted by Klose (1988). The average flow rate was low (0.004 m^3/s) relative to the other point sources; however inputs of BOD_5 (29.4 mg/L), suspended solids (157 mg/L), and TP (2.05 mg/L) were elevated.

The Fort William Division of AbitibiBowater Inc. (legal name Abitibi Consolidated Company of Canada) was a pulp and paper mill that operated at the mouth of the Mission River. In 2000, the allowable daily plant process effluent loading limits were: 4530 kg/day BOD5, 127 kg/day TP, and 6070 kg/day TSS. A 2005 study conducted by George (2012) measured the concentrations of TP and TKN in the surface water at the mouth of the Mission River to be 0.047 mg/L and 0.41 mg/L, respectively; the TP value exceeded the TP-PWQO. The mill was permanently closed in November 2007.

Northern Wood Preservers Inc. is located on the shore of the inner Harbour. For over 50 years, creosoted wood products such as railway ties, telephone poles, and pentachlorophenol treated lumber were produced at the site (Jaagumagi *et al*. 1998). Over time, elevated levels of polycyclic aromatic hydrocarbons (PAHs), chlorophenols (CPs), and dioxins and furans (PCDD/Fs) accumulated in the sediment adjacent to the plant (Santiago 2003). From 1997 to 2003 the contaminated sediments were addressed through the Northern Wood Preservers Alternative Remediation Concept (NOWPARC). The main objectives of NOWPARC were to isolate the contaminant source, remediate the contaminated sediment, and to enhance fish habitat through the use of dredging, a rockfill containment berm, contaminant isolation structures, storm water and groundwater control and treatment, and fish habitat enhancements (Santiago *et al*. 2003). The end result of the remediation effort was the removal, treatment, and reuse of 11 000 m^3 of highly contaminated sediment; containment of 21 000 m^3 of contaminated sediment; isolation of the contaminated site; and the creation of 5 ha of fish habitat (Inch and Santiago 2005). A long term monitoring plan was put in place to measure natural recovery in the harbour area outside of the rockfill containment berm (Inch and Santiago 2005).

Superior Fine Papers, a pulp and paper mill, was located on the shore of the inner north Harbour. The mill was built in 1918 by Abitibi Price Inc., and operated for almost 90 years under different owners. The mill changed hands three times since 2007, but has not been operational since then

(with the exception of four months in 2007). The current owner, Reliance Development Corporation, is in the process of decommissioning the site. Canada and Ontario have committed to developing a sediment management strategy for the North Harbour site under the 2014 *Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health.* A significant amount of work has been completed towards this strategy, including a risk assessment which concludes that the site poses risks to human health and the environment. The risk assessment recommends a 9.9 hectare area for active remediation, such as dredging or isolation capping, and a 15.8 hectare area for passive remediation, such as thin-layer capping (Franz Environmental Inc. 2013). The final sediment management options report recommends dredging and disposal at an existing confined disposal facility as the preferred option (Cole Engineering Group Ltd. 2015). The federal government is the lead for the project because the majority of the contaminated water lot is federally-owned (Transport Canada), and administered by the Thunder Bay Port Authority.

4.5 Invasive Species Strategies

The Stage 1 and 2 Thunder Bay RAP documents (Thunder Bay Remedial Action Plan Team 1991, 2004) expressed concerns regarding the presence of the spiny water flea and zebra mussels. With regard to invertebrates, the Lake Superior Aquatic Invasive Species Guide (Ontario Federation of Anglers and Hunters 2014) has listed the spiny waterflea (*Bythotrephes longimanus*) as the only invasive plankton identified in lake-wide in Lake Superior to-date. It was first identified in 1987 (Lake Superior Binational Program 2014) and was introduced via ballast water.

Fish communities in Lake Superior, both nearshore and offshore, have a diet primarily of the macroinvertebrates *Mysis* and *Diporeia* (Gamble *et al.* 2011a, 2011b). In the lower lakes, Diporeia populations have decreased as a result of the increased abundance of dreissenid mussels (Dermott and Kerec 1997; Nalepa *et al*. 2007, Watkins *et al*. 2007); however this has not been the case in Lake Superior due to the low biomass of dreissenids (Grigorovich *et al*. 2003). In Lake Superior, the presence of dreissenids is confined to near shore areas, as the off-shore surface water is too cold to support a viable population. As such, the populations of diet items such as *Mysis* and *Diporeia* are not presently at risk.

The spiny water flea is predacious, feeding on native crustacean zooplankton such as *Daphnia*, and therefore reducing food for other native zooplankton and small fishes (Lake Superior Binational Program 2014). In terms of being prey, *Bythotrephes* is consumed mostly by larger juvenile and adult fish (Keeler *et al*. 2015). Gamble *et al*. (2011a) found that presence of *Bythotrephes* in Lake Superior has resulted in the incorporation of this species into the diet of some fish. In Gamble's study (2011a), it was determined, via stomach content, that an important component of the diet of Cisco and Lake Whitefish in the late summer and fall was *Bythotrephes*. Offshore of Stockton Island in the Apostle Islands Lakeshore in Lake Superior, Keeler *et al*. (2015) found that between September and November, 1.4% and 839% of *Bythotrephes* production was consumed by small Cisco and large Cisco, respectively, in the intermediate and offshore sites. Small Bloater and large Lake Whitefish also consumed *Bythotrephes* (at a production rate) of 8% and 8.1%, respectively. In the offshore area, the consumption rate exceeded the production rate in all observed instances; however this ratio

decreased towards shore where consumption was not observed. It was noted that no Cisco were present in the nearshore area, and that consumption was observed at the nearshore site in Lake Michigan (Keeler *et al*. 2015). From the perspective of controlling the *Bythotrephes* populations, it would appear that Cisco could serve as a top-down control in some instances. That being said, there are thought to be several factors that influence the dynamics of *Bythotrephes* – depth, temperature, prey resources – and further research is required to fully understand this invasive species (Keeler *et al*. 2015).

The food web configurations determined by Gamble *et al*. (2011a 2011b) were similar to other large, stable oligotrophic systems. Based on the indications that food web complexity is positively associated with community-level stability, it was assumed that the community-level stability of Lake Superior was low given the low levels of food web complexity present (Gamble *et al*. 2011b). However, Gamble *et al.* (2011b) applied the Quirk-Rupert sign-matrix for system stability to the Lake Superior data and found that the organization of the food web was stable at the lower levels. Schmidt *et al*. (2009) found that over the last century the food web of the native Lake Superior fish community has remained stable and has been able to accommodate the introduction of non-native fish species.

There are a number of programs, both provincially and federally, that address the prevention and management of aquatic invasive species (AIS): Ontario Ministry of Natural Resources and Forestry - Invasive Species Plan; federal – Invasive Alien Species Strategy for Canada; Canadian Council of fisheries and Aquaculture Ministers – Canadian Action Plan to Address the Threat of Aquatic Invasive Species. Specific to Lake Superior, the Lake Superior Partnership Working Group developed the binational Lake Superior Aquatic Invasive Species Complete Prevention Plan (Lake Superior Binational Program 2014) under the Lake Superior Lakewide Action and Management Plan. In general the plan outlines recommendations for new actions, as well as promoting existing efforts, to prevent invasive species from both entering and establishing in Lake Superior. Steps have been taken towards fulfilling the actions outlined in the Complete Prevention Plan, specifically with regard to early detection monitoring and prevention education.

5.0 Conclusions

The assessment of plankton populations and communities is complex. The complexity is magnified when assessed within the confines of the AOC model, which uses a limited number of indicators (BUIs) to define a plethora of issues, and Remedial Action Plans to direct remediation and/or restoration. The limitations of this approach are clear in the Thunder Bay AOC, where issues such as eutrophication and the introduction of invasive species were originally identified through the RAP process. These issues must be addressed in some manner, and therefore the *Degradation of Phytoplankton and Zooplankton Populations* BUI box gets checked at the onset of the program. However, practitioners do not always support a common assessment approach with regard to the *Degradation of Phytoplankton and Zooplankton Populations*. Inconsistencies across AOCs existed with the description of impairment, and have continued for two decades in both monitoring and reporting efforts. The lack of consensus on the proper assessment of these

issues, as well as the absence of a defensible baseline prior to determination of BUI status, has made it difficult to properly assess the status of this BUI.

This report deviated from the approaches previously taken to assess the plankton BUI and investigated the current status of the issues that were originally identified as cause for the plankton population degradation. Different lines of evidence were examined in depth to provide a status determination on this BUI. Currently the status of the BUI is requires further assessment.

The nearshore of the Thunder Bay AOC, which includes the Kaministiquia River, is industrialized and urbanized, and there are many possible sources of nutrients and contaminants. To add to the complexity of this environment, the receiving Lake Superior is oligotrophic and cold, which makes it physically and chemically different from the other select lower Great Lake AOCs that have the plankton BUI listed as impaired or requiring further assessment. There have been several studies which have characterized the nearshore and offshore zones of Thunder Bay (Hopkins 1986, Simpson 1987, Anderson 1986, Boyd 1990, Richman 2004, Benoit *et al*. 2012, George 2012). This assessment focused mainly on the nearshore zone of the Thunder Bay AOC, as the plankton would be most likely influenced by anthropogenic inputs in this area. Generally the aforementioned studies found the nutrient levels to be highest in the delta area of the Kaministiquia River, where in most cases, the TP levels exceed the TP-PWQO (20 µg/L in lakes and 30 µg/L in rivers). Despite the elevated levels of TP, nuisance algae has not been reported during the monitoring surveys, which is likely due to the capacity of the Lake to dilute concentrations of TP below the level that would cause algal blooms.

There continues to be three main point sources of nutrients and contaminants to the Thunder Bay AOC: Resolute Forest Products and Ontario Power Generation, Thunder Bay Thermal Generating Station, and the Thunder Bay Water Pollution Control Plant. The inputs from Resolute Forest Products and Ontario Power Generation, which are regulated through the Municipal-Industrial Strategy Abatement regulations and Environmental Compliance Approvals, have had no monthly violations of loading limits since the mid-2000s. In fact, treatment upgrades and/or decreased production rates over time have resulted in a significant decrease in loading levels. Secondary treatment upgrades to the Thunder Bay Water Pollution Control Plant, which is regulated through Environmental Compliance Approvals, have substantially improved the quality of effluent. In addition to the decrease in loading from operating industries, there have been several significant point source contributors that have closed in the past decade and beyond, further improving the quality of the receiving environment.

Toxicity is an indicator that is often used to assess the quality of the effluent. Resolute Forest Products and Ontario Power Generation are both required, under MISA regulations, to conduct acute and chronic toxicity tests at identified control points on a specified schedule (dependent upon previous results). Currently, there is minimal cause for concern with respect to the effluent streams at Ontario Power Generation. There have been no acute toxicity violations since 2006, and very seldom are the potential for chronic effects observed at concentrations less than 100% effluent. With respect to Resolute Forest Products, there has been minimal acute toxicity over the sampling period of 2002 to 2015. Where violations (failures) did occur, they were most often due to a specific operational change (e.g., shutdown). Prior to the past year and a half, effluent

from the combined-mill outfall has posed a potential for chronic impairment to plankton; current data does not indicate a potential for chronic toxicity. It is noted that the assimilative capacity of the Kaministiquia River (XCG Consultants Ltd. 2005) is such that, based on available present day chronic toxicity data, there would be no chronic impact to plankton at a distance in excess of 13.5 m downstream from the diffuser.

A high-level generalized view of the status of the planktonic trophic level employed a top-down and bottom-up approach (Benoit *et al*. 2012). Although the approach was not uniformly supported by all technical experts, it provided a pragmatic screening level assessment of the issue. From the bottom-up, it was shown that the study area was not phosphorus limited, and that chlorophyll-*a* concentrations were not likely to result in undesirable levels of algae (Benoit *et al*. 2012). From the top-down, current data (Foster 2012, Marshall 2015) suggests that the Thunder Bay AOC supports a more diverse fish community than adjacent areas. This screening level top-down, bottom-up approach concluded that there was no basis to recommend a full plankton assessment.

One of the primary issues of concern with regard to this BUI was the introduction of aquatic invasive species, specifically the zebra mussel and the spiny water flea (Thunder Bay RAP 1991, 2004). Dreissenid mussels (which include zebra mussels) are not wide-spread through Lake Superior due to the cold water temperatures; however they are present in specific nearshore areas, including Thunder Bay. Fish communities in Lake Superior, both nearshore and offshore, are primarily supported by a diet of *Mysis* and *Diporeia*. In the lower Great Lakes, these populations of these macroinvertebrates have declined as a result of the abundance of dreissenid mussels; given the physical constrictions this has not been the case in Lake Superior. With respect to the spiny water flea (*Bythotrephes*), there are limited studies that have been conducted in Lake Superior and further research is required to fully understand this invasive species. Trophic food web studies (Gamble *et al*. 2011a, Gamble *et al*. 2011b, Keeler *et al*. 2015) have shown that some fish species, predominantly Cisco, have incorporated *Bythotrephes* into their diet. In specific cases, this adopted feeding behaviour may serve as a top-down control of the invasive population (Keeler *et al*. 2015). Overall, based on the food web configuration at a low level of prey diversity, there is system stability (Gamble *et al*. 2011b). Regardless of the indications of adaption to the invasive species, the issue is a top priority and there are a number of provincial, federal, and binational initiatives that focus on monitoring and prevention.

In conclusion, the assessment of the key factors that influence the health of the plankton population has demonstrated that there is no reason to suspect impairment of the plankton community within the AOC. The industrial landscape of the Thunder Bay AOC has changed substantially since the inception of the RAP program, and concerns of nutrient and contaminant loading are no longer as significant an issue they once were. The assimilative capacity of the large Kaministiquia River and receiving oligotrophic Lake Superior have provided an environment that is not prone to algal blooms, and which supports a healthy fish population. At this time, it is recommended that the 'requires further assessment' status of the Degradation of Phytoplankton and Zooplankton Populations BUI be removed from the Thunder Bay AOC. The lower food web of the lake, as a whole, will continue to be assessed through the Lake Superior Partnership by way of the Coordinated Science and Monitoring Initiative.

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